OPTICAL-IR SPECTRAL ENERGY DISTRIBUTIONS OF $z > 2$ GALAXIES [a b]

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Broadband optical and IR spectral energy distributions are determined for spectroscopically confirmed $z > 2$ Lyman break objects in the Hubble Deep Field. These photometric data are compared to spectral synthesis models which take into account the effects of metallicity and of internal reddening due to dust. It is found that, on average, Lyman break objects are shrouded in enough dust (typically $E(B-V) \approx 0.3$) to suppress their UV fluxes by a factor of ~ 20. Furthermore, these objects are dominated by very young (< 0.2 Gyr) stellar populations, suggesting that star formation at high redshift is episodic rather than continuous.

1 Introduction

A number of spectroscopically-confirmed $z > 2$ Hubble Deep Field (HDF) galaxies have been reported over the course of the last year (Steidel et al. 1996b, Lowenthal et al. 1997). The availability of both the optical and infrared images of the HDF permits us to construct broadband spectral energy distributions (SEDs) for these galaxies. These SEDs sample the rest-UV and -optical, and hence contain information about the galaxies' dust content and ages of stellar populations. Here, we outline the results of fitting these SEDs with spectral synthesis models; full details of this work are described by Sawicki & Yee (1997).

2 Data

We used the Version 2 optical (Williams et al. 1996) and Version 1 Kitt Peak IRIM infrared (Dickinson et al. 1997) images of the Hubble Deep Field. Object finding and photometry were carried out using the PPP faint object photometry package (Yee, 1991), while photometric calibrations were done using the zeropoints provided by the STScI and Kitt Peak HDF teams.

We have measured broadband spectral energy distributions for the seventeen $z > 2$ objects listed in the catalogs of Steidel et al. (1996b), and Lowenthal et al. (1997). (One of the Steidel et al. objects appears to consist of two distict subclumps which we have treated as two objects at a common redshift).

[a]Based on observations made with the NASA/ESA *Hubble Space Telescope* obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

[b]Based on observations made at the Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

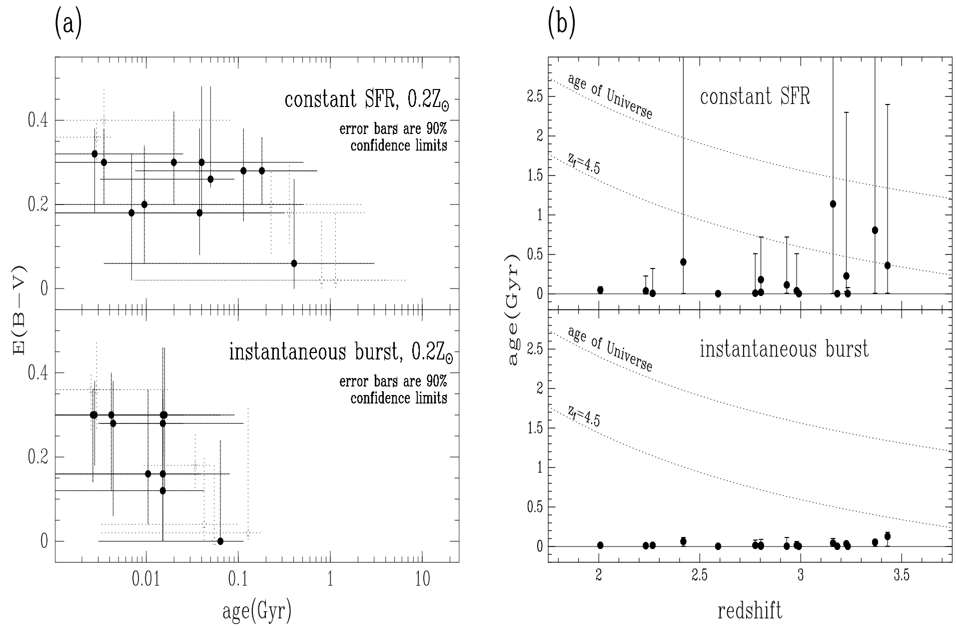

Figure 1: **(a)** Reddening and age of $z > 2$ objects. The top panel shows the constant SFR fits and the bottom one is for the instantaneous burst model. Age means the time since the onset of star formation. Galaxies at $z < 3$ are shown as solid symbols while those at $z > 3$ use broken ones. Error bars correspond to 90% confidence limits. **(b)** The ages of domiant stellar populations of $z > 2$ HDF objects obtained by fitting $0.2Z_\odot$ model SEDs. Error bars correspond to 90% confidence limits. The broken lines are the age of the universe and the age of an object which formed at $z_f = 4.5$ (both are for a $\Omega = 1$ universe whose present-day age is fixed at $t_0 = 12.5$ Gyr). As is reflected in the sizes of uncertainties, objects at $z > 3$ suffer from poor coverage above ~ 4000 Å and, consequently, have less precise age estimates. Stellar populations of the majority of $z > 2$ HDF galaxies appear to have undergone recent ($t < 0.2$ Gyr) episodes of star formation.

3 Model SEDs

The observed broadband SEDs were fitted with GISSEL (Bruzual & Charlot, 1996) multi-metallicity models, which had been reddened with Calzetti's (1997) reddening recipe. Time since the onset of star formation ("age") and the amount of reddening were free parameters. The fits were done using the V_{606}, I_{814}, J, H, and K, bands; the U_{300} and B_{450} bands were not used so as to avoid the stochastic nature of high-z intergalactic attenuation (Madau, 1995) and the poorly-known shape of the reddening law blueward of 1200 Å.

4 Results

Figure 1a shows the ages and reddening parameters of the HDF $z > 2$ galaxies, obtained by fitting $0.2Z_\odot$ model SEDs. Note that the vast majority of objects requires substantial amounts of internal reddening, with $E(B - V) \approx 0.25$ being typical. Objects marked with broken symbols are at $z > 3$; due to bandpass shifting they have only one filter above rest-4000 Å and hence have poorly constrained ages.

Figure 1b summarizes the ages of the best-fitting models. The instantaneous

burst and constant SFR scenarios can be regarded as limiting cases, with the actual star formation history, and hence age of the dominant stellar population, falling somewhere in between these two extremes. Note that most of the high-z HDF galaxies seem to have undergone recent ($t < 0.2$ Gyr) bursts of star formation

5 Implications

The $z > 2$ HDF galaxies are best fitted with models containing intrinsic reddening, with typical values of $E(B-V) \approx 0.25$. Presence of dust has important implications for estimates of star formation or metal ejection rates based on UV luminosities: at 1500 Å, $E(B-V) = 0.3$ will attenuate rest-1500 Å flux by a factor of ~ 20 (see also Meurer et al. 1997; Meurer, this volume; Calzetti 1997). UV-based estimates of star formation and metal ejection rates at $z > 2$ (e.g., Steidel et al. 1996a; Madau et al. 1996; Lowenthal et al. 1997) have to be adjusted accordingly.

The dominant stellar populations of $z > 2$ HDF galaxies appear to be very young, consistent with having undergone a burst of star formation within 0.2 Gyr prior to being observed. The apparent deficit of older (age > 0.2 Gyr) stellar populations at $z < 3$ suggests that star formation in high-redshift galaxies is episodic rather than continuous. While a continuously star-forming stellar population would sustain its luminosity, a short-duration one will fade by ~ 4 magnitudes in 0.2 Gyr after the end of the burst, and hence will no longer be detectable. The HDF high-z galaxies could therefore represent a very select group of objects which had recently undergone bursts of star formation and will fade out of the sample in a few hundred Myr.

6 References

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